

José Mario Molina: Life and legacy of a man who helped to save Earth's ozone layer

Rodolfo Dirzo^{a,b,1} and Adrián Fernández^c

On October 7, 2020, history entrusted us with a moment of profound significance where we rejoiced to see two distinguished women—Emmanuelle Charpentier and Jennifer Doudna—be honored with the Nobel Prize in Chemistry, while we also reckoned with the shattering loss of a much respected and honored academic, a humble and generous man dedicated to the understanding of how our planet functions, and to the virtues and values of striving toward a better world for all to live and thrive in: Dr. Mario Molina, 1995 Nobel Laureate in Chemistry.

José Mario Molina was born in Mexico City on March 19, 1943. Enjoying the benefit of role models, like his father, a lawyer and professor at the National University of Mexico (UNAM), and the Mexican Ambassador to Australia, Ethiopia, and the Philippines, Mario was raised within the atmosphere of an educated and supportive family. From an interview with Mario's brother, Roberto, we can glimpse the early life of Mario, who already showed a clear interest for science (telephone interview with Roberto Molina on October 29, 2020). Mario enjoyed looking at microorganisms through a toy microscope and transformed a home bathroom into his first chemistry laboratory, where he enjoyed investigating, using toy chemistry sets. His aunt, Esther Molina—also a chemist—stimulated that interest by helping him undertake more sophisticated experiments in that “bathroom lab.”

Noticing Mario's scientific potential, his parents sent him, at age 11, to Switzerland for 2 years to learn German, a language then deemed critical to pursue a scientific path. Back in Mexico, after high school, Mario enrolled in UNAM's School of Chemistry in 1960, where he graduated as a chemical engineer. It is from this period that Mario's life-long friend, Dr. Francisco Barnés, also a chemistry major at UNAM (and future President of UNAM), remembers Mario as “a brilliant student” and recalls this amusing anecdote (telephone interview with Dr. Francisco Barnes on October 29, 2020). In one of the classes, Professor Pascual (famous for never awarding the highest marks to anyone) gave Mario an 8/10. Unsatisfied,



José Mario Molina at MIT in 2002. Image credit: L. T. Molina (photographer).

and, despite being a quiet, introverted person, Mario requested a proctored reevaluation with a panel of three professors (including Pascual). The examination's results were excellent, and the panel suggested awarding Mario a 9; but Pascual, quite impressed, gave out his first 10 to Mario!

After his undergraduate studies, Mario went to Germany, where he studied polarization kinetics at the University of Freiburg for 2 years, after which he returned to his alma mater, UNAM, where he became an assistant professor and spear-headed the development of the first graduate program in chemical engineering. Eager to expand his scientific horizons, Mario decided “to study various basic subjects in order to broaden [his] background and to explore other research areas” (1). In 1968 Mario joined the graduate program in physical chemistry at the University of California, Berkeley. There, he took courses in mathematics and physics in addition to core requirements and, critically, joined the group of Prof. George Pimentel.

^aDepartment of Biology, Stanford University, Stanford, CA 94305; ^bWoods Institute for the Environment, Stanford University, Stanford, CA 94305; and ^cDivision de Equipo Operativo, Iniciativa Climática de México, 03100 Mexico City, Mexico

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¹To whom correspondence may be addressed. Email: rdirzo@stanford.edu.

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The academic atmosphere of the group was captivating, and Pimentel was an outstanding, socially conscientious mentor, remarkable researcher on chemical laser theory, charismatic teacher, and a tremendously positive influence on the laboratory members, according to Luisa Tan, an advanced graduate student of the Pimentel laboratory and later Mario's wife and central collaborator (telephone interview with Dr. Luisa T. Molina on October 21, 2020). Luisa also shared that Pimentel regarded Mario as one of the best students he ever had; clearly, the appreciation and admiration were bidirectional. Mario once wrote (1) that George Pimentel was "an excellent teacher and a wonderful mentor; his warmth, enthusiasm, and encouragement provided me with inspiration to pursue important scientific questions." Some of the questions they examined, and published together, address theoretical and experimental analyses of chemical laser studies (2, 3). In his autobiography (1), Mario states that his years in Berkeley were some of the best of his life because of his own scientific growth, the Berkeley activism culture, and the profound friendships he developed, particularly with Luisa and Francisco Tablas. Tablas was instrumental in helping Mario develop the experimental skills he needed for his research. Immersed in Berkeley's atmosphere, Mario gained an invaluable awareness of the impacts of science and technology on society, noticing, for example, that the high-powered chemical lasers he had used as research tools were also being developed elsewhere as weapons (1).

In 1973, Mario took a postdoctoral position in Prof. Sherwood (Sherry) Rowland's laboratory at the University of California, Irvine, investigating the fate of chlorofluorocarbons (CFCs) once released into the atmosphere. A few months later they published their 1974 landmark paper in *Nature* (4), where they brought to light the problem of the thinning of the ozone layer resulting from the use of CFCs: "The CFC-ozone depletion hypothesis." After his postdoctorate, Mario was appointed faculty in Irvine where he continued collaborating with Rowland. In 1982, Mario and his closest academic colleague, his wife Luisa, moved to the Jet Propulsion Laboratory, where their strong collaboration led to numerous publications (e.g., refs. 5 and 6), including those that explain the mechanisms by which CFCs lead to the ozone layer depletion. A wonderful technical (and yet friendly) summary of this amazing scientific saga is given in Mario's Nobel Lecture (7).

Twenty-two years after the publication of the *Nature* paper (4), Rowland and Molina's work, together with that of Paul Crutzen, led them to receive the 1995 Nobel Prize in Chemistry. After the Nobel, Mario's life became hyperhectic. Among many other things, he contributed to the drafting of the momentous Montreal Protocol that led to the regulation and phasing out of CFCs, which epitomizes one of Mario's greatest aspirations: To put science to the service of policy to effectively address problems of humanity.

Not surprisingly, Mario's qualities lay beyond just a gifted mind. As Dr. Barnés observes, Mario used part of his Nobel Prize money to fund students and researchers to train in his laboratory in the United States,

a testimony to his generosity (telephone interview with Dr. Francisco Barnes on October 29, 2020). His appreciation for students is made evident in this statement (1): "I have also benefited from teaching; as I try to explain my views to students with critical open minds, I find myself continually challenged to go back and re-think ideas. I know teaching and research as complementary, mutually reinforcing activities." Mario's full immersion in academic life occurred when the Molinas moved to the Massachusetts Institute of Technology (MIT) in 1989. Together, they developed The Integrated Program on Urban, Regional, and Global Air Pollution, involving investigators from MIT, Harvard's School of Public Health, and other United States and international institutions, many of them from Mexico. The program focused on "integrated assessments" of different emissions-reduction strategies, considering scientific-technological factors, socioeconomic and political dimensions of the problem, and possible actions that could be taken. Dr. Luisa Molina, then Director of the program, described this period as an effervescent time of truly interdisciplinary work. With support from Mexico's Instituto Nacional de Ecología, the Molinas started an MIT-Harvard joint master's program, which helped to train some of today's environmental leaders in Mexico. The Instituto Nacional de Ecología also hosted the "Milagro" research initiative, the largest air-quality monitoring, modeling, and assessment project ever conducted in a megacity.

In time, Mario's discoveries became increasingly appreciated, with him even serving on the President's Council of Advisors on Science and Technology under Bill Clinton and Barack Obama, and culminating in 2013 when he received the Presidential Medal of Freedom from President Obama. In the ceremony, President Obama said: "Thanks to Mario's work the world came together to address a common threat, and today inspired by his example, we are working to leave our planet safer and cleaner for future generations."

After 15 years at MIT, Mario returned to California in 2004, with a position in the Department of Chemistry and Biochemistry and the Scripps Institution of Oceanography at University of California San Diego (UCSD); he remained associated with UCSD until his death. Mario's professorship at UCSD was a split position, as he spent considerable time in his native Mexico City, where he founded the Centro Mario Molina (CMM). At CMM he led work to address the problem of pollution in the metropolis, particularly Mexico City, and tirelessly advocated global action for a wiser use and conservation of the planet's life-supporting systems. From CMM's inception, we witnessed how Mario became Mexico's environmental and scientific conscience, his wisdom and modesty enthralled presidents, ministers, governors, congress representatives, and the public. For example, the day before he died, Mario signed a newspaper petition asking for the expansion of bike paths in Mexico City.

The enormous privilege of having shared a recognition with Mario, as Pew Scholars in Ecology and the

Environment, sparked a professional interaction that was nurtured until this year: We participated in several fora and events where we addressed diverse aspects of global change, including the climate change–biodiversity relationships, and the significance thereof for human well-being. We also participated in panels related to science education for youth both in Mexico and California. Mario’s efforts on this front are remarkable for a person engaged in so many other enterprises. Our interactions with Mario have given us invaluable opportunities to witness his remarkable dedication to the cultivation of the scientific enterprise for the betterment of humankind, but his outstanding bonhomie and humble character were his truly remarkable qualities.

The oft-cited sentence from Sir Isaac Newton, “If I have seen further than others, it is by standing upon the shoulders of giants” (from a letter written to fellow Robert Hooke in February 1675; The Newton

Project, <http://www.newtonproject.ox.ac.uk/>), brings back conversations with Mario, for whenever we mentioned our admiration for his accomplishments, he always responded with a statement similar to Newton’s. This is also beautifully expressed in his autobiography (1): “I feel that this Nobel Prize represents a recognition for the excellent work that has been done by my colleagues and friends in the atmospheric chemistry community on the stratospheric ozone depletion issue.” This statement shows his bonhomie, humble character, and empathy, and we believe this is a splendid indication of how this wonderful human being can be remembered.

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